NAME:

75 MINUTES; HAND IN YOUR SHEETS OF NOTES WITH THE EXAM; ASK FOR EXTRA PAPER IF NEEDED. MAKE (AND STATE) ANY REASONABLE ASSUMPTIONS NECESSARY TO GET AN ANSWER IN ADDITION TO THOSE GIVEN. CHECKING WHETHER THE ANSWER MAKES SENSE MAY HELP YOU EARN PARTIAL CREDIT IF YOU WENT WRONG SOMEWHERE.

PROBLEM 1 (60 pts total): Consider the large industrial source described below.

Environment: Big city, sunny winter day. Lapse rate: -10 K/km.
Wind speed at 10 m above ground = 3.5 m/s
T = 270 K, P = 1 atm, upwind NOx concentration = 10 µg/m^3
Emissions: An emission source is located at x = 0m and y = 0m, with characteristics:
E = 10^4 g NOx/s, h = 90m, Δh = 10m
Receptor: Located at x = 700m, y = 100m, z = 0m

(a) (50 pts) Determine NOx concentration at the receptor in units of µg/m^3 using the Gaussian plume model.

*Based on the lapse rate, the stability class is D. The effective plume height is H = h + Δh = 100m. No inversion is mentioned, so use first form of GPM. From T7.7, the windspeed exponent is p = 0.25 (rough terrain); therefore, v(100 m) = 3.5 * (100/10)^0.25 = 6.2 m/s. Since x < 1 km at the receptor, we have from T7.14 a = 68, c = 33.2, d = 0.725, f = -1.7. So $\sigma_y = 68 * (0.7)^{0.894} = 49$ m, $\sigma_z = 33.2 * (0.7)^{0.725} - 1.7 = 24$ m. The GPM gives us C = 9.1E-6 g/m^3. Adding the upwind concentration, we have C_{tot} = 19 µg/m^3.*

(b) (10 pts) Qualitatively, how would you expect the answer to change if there was an inversion at a height of 150 m? Why?

The concentration at the receptor would probably be higher, because the inversion layer impedes the plume from spreading vertically, so more pollutant remains near the surface.

PROBLEM 2 (30 pts)

Children in a school are exposed to dust from an upwind construction site. Assume that the dust concentration at the school due to the construction averages 20 $\mu g/m^3$. Assume that each child weighs 20 kg and is exposed to the dust for 25 hours per week over 1 year. Evaluate the risk of death from cancer and the hazard ratio for the children.

Given: dust reaction rate = 11.52 day^{-1}, potency factor = 4.68 x 10^{-5} $(mg/kg\text{-}day)^{-1}$, reference dose = 10^{-9} mg/kg-day, bioconcentration factor = 100 L/kg

CDI: (20 m^3 air / day)(0.02 mg dust/m^3 air)(25 hours/week)(1 year) / (168 hours/week)(70 years) (20 kg) = 4.3E-5 mg/kg-day.

Cancer risk: (4.68 x 10^{-5})(4.3E-5) = 1.83E-9 < 1E-6, potentially acceptable

Hazard ratio: (4.3E-5)/1E-9 = 4.3E+4 > 1, unacceptable

PROBLEM 3 (10 pts):

Concisely (in a couple of sentences) define each of the terms below and explain how it is relevant to environmental impacts.

IRIS

The EPA's Integrated Risk Information System. This is a database on the effects of different substances on human health, which can be used for assessing the health impacts of current or potential pollutants.

PM2.5

Concentration in air of particles smaller than 2.5 microns. These particles are a form of air pollution that is quite hazardous to human health.

NAAQS

National Ambient Air Quality Standards. These are enacted by the EPA under the Clean Air Act to mitigate impacts of air pollution on human health, particularly in cities. Jeopardizing the local or regional attainment of NAAQS would be a serious negative environmental impact.

Greenhouse gas

A gas in earth's atmosphere that absorbs thermal infrared radiation, which has the effect of warming the earth's surface. Concentrations of greenhouse gases such as carbon dioxide rise as a result of many human activities, particularly burning fossil fuels, causing harmful climate change and sea level rise.

Geostrophic wind

The wind due to a pressure gradient on a rotating planet. This is directed counterclockwise around a low pressure center in the northern hemisphere. Wind direction affects air quality by transporting pollutants regionally.

GIVEN INFORMATION

1 m^3 = 1000 L, 1 mg = 10^{-3} g, 1 µg = 10^{-6} g

T(degK) = T(degC) + 273.15, 1 atm = 101325 Pa

$$\mathrm{MW}_i = \frac{\text{mass i}}{\text{mols i}} = \sum_{k=1,K} n_k \mathrm{AW}_k, \quad \mathrm{FW} = \sum_{k=1,K} y_i \mathrm{MW}_i$$

PV=nRT where R=0.08206 L atm mol^{-1} K^{-1}

$$\rho_{air} = \frac{\text{mass air}}{\text{volume air}} = \frac{n_{air} \times MW_{air}}{V_{air}} = \frac{n_{air}}{V_{air}} \times MW_{air} = \frac{P}{RT} \times MW_{air}$$

$$M_i = \frac{\text{mols i}}{\text{L m}} = \frac{\text{mass}_i / \text{MW}_i}{V_w} = \frac{m_i}{\text{MW}_i}, \quad y_i = \frac{\text{mols i}}{\text{mols t}} \approx \frac{\text{mass}_i / MW_i}{\rho_m \times V_m / MW_m} \quad \text{and} \quad \sum_{i=1,I} y_i = 1$$

$$\mathrm{P}_i = y_i \mathrm{P} \quad \text{and} \quad \sum_{i=1,I} P_i = P$$

AW of elements in g/mol: 1 for H, 12 for C, 14 for N, 16 for O, 31 for P, 32 for S

Density of pure water at 1 atm and 4°C = 1000 kg/m^3

$$\frac{d}{dt}\int_{cv} \rho \, d\forall = -\int_{cs} \rho \, V(A) \cdot n \, dA \quad \text{and} \quad \frac{d}{dt}\int_{cv} \rho \, d\forall = \frac{dm}{dt}$$

$$\int_{cs} \rho \, V(A) \cdot n \, dA = -\int_{cs,in} \rho \, V(A) \, dA + \int_{cs,out} \rho \, V(A) \, dA = \sum_{cs,in} \rho \, \bar{V} A - \sum_{cs,out} \rho \, \bar{V} A = \sum_{cs,in} \dot{m} - \sum_{cs,out} \dot{m}$$

Eqn 6.33 $R_i = \pm \sum_{j=1,J} \left[k_j \forall \left(\prod_{h=1,H} C_{i,h} \right) \right]$ **and Eqn 6.34** $K = \dfrac{\prod_{h=1,H \text{ products}} [C_{i,h}]^{c^*}}{\prod_{h=1,H \text{ reactants}} [C_{i,h}]^{c^*}}$

Eqn 6.35 $K = 10^{-pK}$ **and Eqn 6.41** $\sum_{i=1,I} n_{i,j^*} = \sum_{i=1,I} n_{i,j^o}$

Eqn 6.23 $\mathrm{HA_{aq}} \Leftrightarrow H^+_{\mathrm{aq}} + \mathrm{A^-_{aq}}$ **and Eqn 6.24** $A_a B_{b_s} \Leftrightarrow \mathrm{aA^+_{aq}} + \mathrm{bB^-_{aq}}$

Eqn 6.25 $A_{\mathrm{aq}} \Leftrightarrow A_{\mathrm{ads}}$ **or** $A_g \Leftrightarrow A_{\mathrm{ads}}$ **and Eqn 6.26** $A_a B_{b_{(\mathrm{aq})}} \Leftrightarrow A_a B_{b_{(g)}}$

Eqn 7.1 $P_1 + \rho g \, z_1 + \dfrac{\rho V_1^2}{2} = P_2 + \rho g \, z_2 + \dfrac{\rho V_2^2}{2}$ **Eqn 7.8** $E = A \times EF \times (1 - ER/100)$

Eqn 7.2 $V(z) = V(z_{\mathrm{ref}}) \left(\dfrac{z}{z_{\mathrm{ref}}} \right)^p$ **and Eqn 7.3** $Q = \int_A V(A) \, \mathrm{dA} \quad = \dfrac{Y \; V(z_{\mathrm{ref}})}{z_{\mathrm{ref}}^p} \left(\dfrac{Z^{p+1}}{p+1} \right)$

Eqns 7.12 and 7.15: $\Delta h = 2.6 \left(\dfrac{F}{u_h S} \right)^{1/3}$ **(stable);** $\Delta h = 1.6 \dfrac{F^{1/3} x_f^{\,1/3}}{u_h}$ **(neutral/unstable)**

Eqn 7.13 $F = g r^2 v_s \left(1 - \dfrac{T_a}{T_s} \right)$ **, Eqn 7.14** $S = \dfrac{g}{T_a} \left(\dfrac{dT_a}{dz} + 0.01 \dfrac{\mathrm{K}}{\mathrm{m}} \right)$ **,**

Eqn 7.16 $x_f = 120\,F^{0.4}\ \text{for}\ F \geq 55$
$= 50\,F^{5/8}\ \text{for}\ F < 55$

Eqn 7.17 $H = h + \Delta h$ **Eqn 7.18** $x_L = \left(\dfrac{0.47(L-H)-f}{c}\right)^{1/d}$ **Eqn 7.19** $E_i = Qm_i$

Eqn 7.21 $\sigma_y = a\,x^{0.894}$ with x in km and **Eqn 7.22** $\sigma_z = c\,x^d + f$ with x in km

Eqn 7.23 $C(x,y,0) = \dfrac{E}{\pi u_H \sigma_y \sigma_z}\exp\left[-\dfrac{1}{2}\left(\dfrac{y}{\sigma_y}\right)^2\right]\exp\left[-\dfrac{1}{2}\left(\dfrac{H}{\sigma_z}\right)^2\right]\ \text{for}\ x < 2x_L$

Eqn 7.24 $C(x,y,0) = \dfrac{E}{\sqrt{2\pi}\,u\sigma_y L}\ \text{for}\ x \geq 2x_L\ \text{and}\ |y| \leq 3\sigma_y$ **Eqn 7.25** $C^{\text{total}}_{x,y,0} = C_u + C^{\text{plume}}_{x,y,0}$

Atmospheric stability class		Value of exponent p in Equation 7.2	
		Rough terrain	Smooth terrain
A	Very unstable	0.15	0.09
B	Moderately unstable	0.15	0.09
C	Slightly unstable	0.20	0.12
D	Neutral	0.25	0.15
E	Slightly stable	0.40	0.24
F	Stable	0.60	0.36

	Actual temperature lapse rate range (deg K/100m)
A	dT/dz < -1.9 degC/100m
B	-1.9 ≤ dT/dz < -1.7
C	-1.7 ≤ dT/dz < -1.5
D	-1.5 ≤ dT/dz < -0.5
E	-0.5 ≤ dT/dz < 0
F	0 ≤ dT/dz

Atmospheric Stability Classifications

Surface Windspeed[a] (m/s)	Day Solar Insolation: Strong[b]	Moderate[c]	Slight[d]	Night Cloudiness[e]: Cloudy (≥4/8)	Clear (≤3/8)
<2	A	A–B[f]	B	E	F
2–3	A–B	B	C	E	F
3–5	B	B–C	C	D	E
5–6	C	C–D	D	D	D
>6	C	D	D	D	D

[a]Surface wind speed is measured at 10 m above the ground.
[b]Corresponds to clear summer day with sun higher than 60° above the horizon.
[c]Corresponds to a summer day with a few broken clouds, or a clear day with sun 35–60° above the horizon.
[d]Corresponds to a fall afternoon, or a cloudy summer day, or clear summer day with the sun 15–35° above the horizon.
[e]Cloudiness is defined as the fraction of sky covered by clouds.
[f]For A–B, B–C, or C–D conditions, average the values obtained for each.
Note: A, Very unstable; B, moderately unstable; C, slightly unstable; D, neutral; E, slightly stable; F, stable. Regardless of windspeed, class D should be assumed for overcast conditions, day or night.

		$x \leq 1$ km			$x \geq 1$ km		
Stability	*a*	*c*	*d*	*f*	*c*	*d*	*f*
A	213	440.8	1.941	9.27	459.7	2.094	−9.6
B	156	106.6	1.149	3.3	108.2	1.098	2.0
C	104	61.0	0.911	0	61.0	0.911	0
D	68	33.2	0.725	−1.7	44.5	0.516	−13.0
E	50.5	22.8	0.678	−1.3	55.4	0.305	−34.0
F	34	14.35	0.740	−0.35	62.6	0.180	−48.6

Note: The computed values of σ will be in meters when x is given in kilometers.